U.S. PATENT APPLICATION

ENTITLED:

METHOD FOR AUTOMATIC DETERMINATION OF OPTICAL PARAMETERS OF A LAYER STACK AND COMPUTER PROGRAM

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METHOD FOR AUTOMATIC DETERMINATION OF OPTICAL PARAMETERS OF A LAYER STACK AND COMPUTER PROGRAM

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority of the German patent application 102 32 746.7 which is incorporated by reference herein.

FIELD OF THE INVENTION

The invention refers to a method for automatic determination of optical parameters of a layer stack, such as layer thicknesses, refractive indices, or absorption coefficients, by comparing an optical measured spectrum acquired from one location in the layer stack to an analysis spectrum calculated on the basis of specified optical parameter values, and optimizing the calculated analysis spectrum to the measured spectrum. The invention further refers to a computer program (product) for carrying out such a method.

BACKGROUND OF THE INVENTION

Methods of this kind play an important role especially when measuring the layer thickness of thin layers, as well as further optical parameters, such as the refractive index and extinction factor, of single- and multiple-layer systems that represent, for example, patterned wafers.

In the present description, the term "layer stack" encompasses both the layer stack in the narrower sense (sequence of individual layers, for example, SiO_2, Si_3N_4, resist films, etc. on a substrate such as silicon or aluminum) and the combination of a layer stack and substrate.

An optical measurement device for measuring the aforesaid properties on single- and multiple-layer systems in a layer thickness range from approx. 1 nm to approx. 50 µm is known from DE 100 21 379 A1. The latter makes provision for an illumination device, for example a halogen lamp and a deuterium lamp, in order to generate a measurement light beam having a sufficiently broad wavelength range, for example between 190 nm and 800 nm. By means of a beam splitter, the measurement light beam is split into a subject light beam and a reference light beam. The measurement light beam is directed by means of a

measurement objective, with an approximately perpendicular incidence, onto the measurement location of a specimen; and the beam reflected from the specimen is conveyed, together with the reference light beam, to an evaluation device. A suitable evaluation device in this context is a mirror grating spectrograph that images the wavelengths of the incoming light, in spatially separated fashion, onto a CCD detector. The latter is sensitive over the entire wavelength range, and permits a rapid readout of the measured spectra. In the aforementioned document, the reflected subject light beam and the reference light beam are conveyed via light guides to the evaluation unit. The measurement unit described can additionally contain a device that can be incoupled for visual display and monitoring.

With a measurement arrangement according to DE 100 21 379 A1, the intensity values, resulting from interferences, in the spectrum of the subject light beam reflected from the specimen are detected and evaluated in order to determine the optical layer properties. Because of ambiguities (the intensity values are calculated, depending on the layer sequence, from a number of terms that depend on the sine of the phase of the product of the respective layer thickness and the [spectrally dependent] refractive index, and on the refractive and absorption indices themselves), it is not possible, except in special cases, to calculate back analytically from the curve shape to the optical parameters. As a rule, computation-intensive fitting methods must be used.

A number of methods for evaluating the spectrum of the reflected subject light beam are known from the existing art. For example, according to European Patent EP 0 644 399 B1, the layer thickness d of a thin single layer can be determined from the number m of extreme values (maxima and minima) in the spectrum of the reflected subject light beam in the observed wavelength region from λ1 to λ2, using the known formula

$$d = 0{,}25x\frac{m-1}{\frac{n1}{\lambda 1}-\frac{n2}{\lambda 2}} \qquad [(1)],$$

n1 and n2 being the refractive indices of the thin layer at wavelengths $\lambda 1$ and $\lambda 2$, respectively.

With multiple-layer systems, however, a spectrum is obtained in which the interference spectra of the individual layers and of the layers with respect to one another are superimposed, so that equation (1) is no longer immediately applicable. In such a case global and local optimization methods, which are based on theoretical models with specified layer thickness ranges and optimize them in terms of the spectrum that has been determined, can be used. The method according to the aforesaid patent is based on a possible layer thickness range that depends on the total number of extremes, the wavelength of the lowest and highest extreme, and a refractive index of a layer averaged over the wavelength range. By modifying the layer thickness in the particular layer thickness range at predetermined increments for each individual layer, it is possible to identify the layer thickness combination whose calculated spectral reflection exhibits the least deviation from the measured reflection.

The method of EP 0 644 399 B1 does not represent a general method with capabilities for varying the refractive and absorption index, since these optical properties of each layer, as well as the number of layers, must be known. The layer thickness ranges always have zero as the lower limit; only the extreme positions are evaluated.

U.S. Pat. No. 4,984,894 measures the thickness of the topmost layer of a multiple-layer system on the assumption that no light is reflected from the second layer located therebelow.

The aforesaid method is restricted to the topmost layer of a specific layer sequence and to specific layer parameters, and provides only approximate results.

In U.S. Pat. No. 5,440,141 the layer thicknesses of a triple layer system of known composition are determined by using for the topmost layer the extremes method already discussed, and for the two following layers a Fourier transform method together with optimization methods for the layer thicknesses that are obtained. In the Fourier method, the reflection spectrum measured as a function of wavelength

is converted into a spectrum dependent on wavelength, and is then Fourier transformed. In the case of a double layer, the absolute magnitude of the Fourier-transformed spectrum exhibits three peaks: one for each layer and one summed peak. These peaks satisfy the summed relationship, so that non-fitting peaks can be excluded. An optical thickness (nd) value can be allocated to a peak in the Fourier-transformed spectrum if the optical thicknesses are sufficiently thick in relation to the measured spectral region (at least one period in the spectral region).

The aforesaid method of U.S. Pat. No. 5,440,141 is restricted to certain layer combinations of known composition, and cannot be employed for general measurements.

Lastly, U.S. Pat. No. 5,864,633 discloses a method for optical inspection of a film stack (thin-layer stack) in which optical data and theoretical data corresponding thereto are compared, and the theoretical data are adapted by means of genetic algorithms. Each theoretical model here represents a so-called genotype (set of thin-layer parameters) that constitutes a sequenced list of genes (various layer parameters such as thickness, refractive index, extinction coefficient). A genotype thus contains the various layer parameters of all the layers. Firstly a number of genotypes is defined, and for each genotype a fit level, resulting from a comparison between the calculated theoretical data and measured data from optical inspection, is identified. Depending on the fit level, the genotypes are subjected to a genetic operation (copying, crossing, mutation). In this fashion, a new set of genotypes (new generation) can be produced from the existing set of genotypes. When the fit level of the best genotype no longer improves substantially over a number of generations, the procedure is discontinued.

Because of the large number of computation operations and the resulting computation time, this method is not suitable for industrial use in the inspection and mensuration of layered systems.

SUMMARY OF THE INVENTION

It is therefore the object of the present invention to describe a method for automatic determination of optical material properties of a layer stack

that supplies, without restrictions in terms of the number, nature, or thickness of the layers, and with as few computation operations as possible and thus in a brief time, results which permit this method to be used in particular in continuous production lines, for example in wafer fabrication.

This object is achieved by a method for automatic determination of optical parameters of a layer stack, such as layer thicknesses, refractive indices, or absorption coefficients, comprising the steps of:

- acquiring an optical spectrum at one location of the layer stack;
- calculating an analysis spectrum on the basis of specified optical parameter values;
- comparing the acquired optical spectrum to the analysis spectrum;
- optimizing the calculated analysis spectrum to the measured spectrum,
- classifying the acquired measured spectrum on the basis of curve shape parameters that characterize the measured spectrum and are determined therefrom, and
- comparing those curve shape parameters to corresponding spectrum curve shape parameters calculated for known layer stacks in order to determine values or value ranges for the optical parameters to be identified, on the basis of which the analysis spectrum or spectra for comparison with the measured spectrum is/are calculated.

It is a further object of the present invention to provide a computer program for automatic determination of optical material properties of a layer stack.

The above object is achieved by computer program having program code means, the computer program carries out the steps:

- acquiring an optical spectrum at one location of the layer stack;
- calculating an analysis spectrum on the basis of specified optical parameter values;
- comparing the acquired optical spectrum to the analysis spectrum;

- optimizing the calculated analysis spectrum to the measured spectrum,
- classifying the acquired measured spectrum on the basis of curve shape parameters that characterize the measured spectrum and are determined therefrom, and
- comparing those curve shape parameters to corresponding spectrum curve shape parameters calculated for known layer stacks in order to determine values or value ranges for the optical parameters to be identified, on the basis of which the analysis spectrum or spectra for comparison with the measured spectrum is/are calculated,

when the computer program is executed on a computer or a corresponding computation unit.

The classification according to the present invention of the acquired measured spectrum on the basis of characteristic curve shape parameters, and the subsequent comparison to corresponding curve shape parameters calculated for known layer stacks, immediately yields a first result for the optical parameters to be identified. From this, the analysis spectrum is calculated and is compared to the measured spectrum. Depending on the quality of the match, this is followed by further fitting methods as explained below. The aforesaid comparison of curve shape parameters of the classified optical spectra can also yield value ranges for the optical parameters to be determined, those ranges serving as the basis for the subsequent fitting methods.

The critical advantage of the method according to the present invention is the restriction, by means of a comparison of spectral parameters (curve shape parameters), of the possible value range for the optical parameters of a layer stack to be identified; that comparison can be performed relatively quickly by using previously calculated and pre-sorted tables. As a result, substantially reduced value ranges (as compared to existing methods) for the optical parameters to be identified are thus available for the subsequent fitting methods, so that those fitting methods can be implemented substantially more quickly.

The invention will be compared below to a conventional approximation method, as discussed in EP 0 644 399 B1 already mentioned, using the example of a triple layer. The investigation concerns the reflection spectrum in the range from 400 to 800 nm. The total thickness is assumed to be such that several extremes occur:

a) Firstly, all 401 spectral channels are evaluated, and the number of extremes is identified;

b) The layer thickness estimate in accordance with the aforesaid patent is assumed to yield upper limit values of 700 nm, 500 nm, and 400 nm;

c) For the coarse fit, the layer thickness is to be varied in the range from zero to the respective upper limit value, in increments of 10 nm;

d) The result is assumed to be 70 x 50 x 40 = 140,000 support points for the thickness calculation, i.e. 140,000 spectra must be calculated and compared. This is then followed by the so-called fine fit, in which the local minimum is identified exactly in a further iteration procedure. Here again, a theoretical spectrum is calculated in each iteration step.

In the example discussed, only the layer thicknesses were to be determined as optical parameters. Further parameters, such as the refractive index or absorption coefficient, are involved multiplicatively in both the coarse and fine fitting operations, so that the number of support points can rapidly amount to several million. In the example cited, typical evaluation times exceed those that make the method suitable for continuous industrial use.

The method of the aforesaid patent described by way of example has the further disadvantage that a value of zero must always be assumed as the lower limit for the layer thickness, if no further limitations are specified. If the parameter space is too severely restricted in order to shorten analysis time, incorrect evaluations can occur. If the parameter space is searched too coarsely for local minima, there is a large residual risk in terms of misinterpretation of the data and an evaluation that leads to incorrect results. In addition, interference effects can cause the determination of the number of extremes to be incorrect, an error that affects the

determination of upper limit values for the layer thicknesses and propagates correspondingly.

For time-related reasons, a restriction of the parameter space for evaluation is highly desirable, especially as the number of layers increases.

According to the present invention, the acquired measured spectrum is classified by means of characteristic curve shape parameters, on the order of five to 15 such parameters generally being sufficient. The curve shape parameters of the acquired measured spectrum are then compared to the tabulated curve shape parameters of known spectra, individual values or a value range being obtained as the result for each optical parameter to be identified. Consequently, with the invention it is initially not spectra comprising 400 to 600 values, but rather table entries (having approx. 10 values), that are compared to one another, yielding a considerable reduction in computation capacity and time. The critical factor in the time savings is that calculation of a spectrum using a complex formula requires much more time (by a factor of 100,000) than comparison with the table entries.

Classification of the measured spectrum is accomplished on the basis of one or more of the following characteristic curve shape parameters: local noise of the spectrum; mean; standard deviation of the mean; number and location of extremes; a classification of the extremes, e.g. as to spectral location; intensity values or relative spacings between them; parameters of enveloping curves of the minima and maxima; averaged curve profile; beats; and possibly further parameters such as the number of peaks in the Fourier-transformed spectrum.

A restriction or filtering of the value ranges for the optical parameters to be determined is accomplished, for example, by comparing the spectral parameters to prefabricated parameter lists (tables) and, depending on the layer stack, additionally by means of an extremes method and/or a Fourier transform method. Examples of such methods are, as already mentioned, known from the existing art.

Determination of the optical parameters of the layer stack under examination can then advantageously be accomplished, on the basis of the restricted parameter space, using known coarse and fine fitting methods, for example by means of grid,

interval, and/or Powell methods. Conformity between the measured and analysis spectrum is then evaluated and the "best fit" is selected.

If the method described does not lead to plausible results, the restricted parameter space can, if applicable, be expanded and the method can be run through again.

The structure of the layer stack, i.e. the composition sequence of the individual layers, is often known. If not, in an embodiment of the method according to the present invention for which protection is claimed separately, in a first step an automatic determination is made of the composition sequence of the layer stack by once again acquiring a measured spectrum and classifying it on the basis of characteristic curve shape parameters, and determining, by comparison with corresponding curve shape parameters of spectra belonging to layer stacks of known composition, one or more possible sequences of layer stack composition.

In this case as well, an analysis spectrum can furthermore be calculated on the basis of the layer stack composition results, and optimized to the measured spectrum using fitting methods. At the same time, in addition to a possible layer stack composition sequence, the layer thickness ranges, refractive index ranges, and further ranges for the relevant optical parameters can also be identified. A much larger parameter space must be searched in this case, so that it is advantageous to perform this preliminary determination of the layer stack composition and its optical parameters in the background, for example simultaneously with programming of the stage positions.

The spectral parameter space to be searched can often be restricted by specifying the possible layer/substrate combinations that will be used by a customer. The method according to the present invention then searches a priori through the most probable combinations (and associated optical parameter regions) of the available possibilities.

It is advantageous to display the results found in this preliminary determination to the customer, and to give him or her the opportunity to accept or correct the result.

The determination according to the present invention of optical parameters of a layer stack, along with possible determination of the chemical composition

sequence of the layer stack, is advantageously performed by means of a computer program that is executed on a suitable computation unit. The data determined (value ranges for optical parameters, layer composition) can be displayed in the usual manner on a monitor. The customer can furthermore be offered the capability of influencing the displayed data. The computer program can be stored on suitable data media such as EEPROMs or flash memories, but also on CD-ROMs, diskettes, or hard drives. A transfer of the computer program via a communication medium (such as the Internet) to the customer (user) is also possible.

BRIEF DESCRIPTION OF THE DRAWINGS

An exemplary embodiment of the invention and its advantages will be explained in more detail below with reference to the attached Figures, in which:

FIG. 1 shows two measured spectra of a double layer (FIG. 1a) and a single layer (FIG. 1b) on a substrate;

FIG. 2 shows the "Number of Extremes" curve shape parameter plotted against the optical thickness of a calculated parameter list for the aforesaid double layer;

FIG. 3 shows the spectrum Mean as the curve shape parameter plotted against the optical thickness of a parameter list calculated for the aforesaid double layer;

FIG. 4 shows the wavelength value of the maximum closest to the long-wave end of the measured spectrum as the curve shape parameter of the calculated spectrum, plotted against the optical thickness of the parameter list calculated for the aforesaid double layer;

FIG. 5 shows the Maximum Value as the curve shape parameter plotted against the optical thickness of the parameter list calculated for the aforesaid double layer;

FIG. 6 shows theoretical spectra of similar appearance.

DETAILED DESCRIPTION OF THE INVENTION

The invention will be explained below with reference to the simple example of a double layer on a substrate, but is by no means limited to that specific case. The example makes use of a Si3N4-SiO2-Si combination (Si as substrate). For the method according to the present invention discussed below, the composition sequence of the layer stack is therefore known in this case.

The table below represents one example of a prefabricated calculated parameter list for the aforesaid double layer, the curve shape parameters below having been derived from the relevant calculated analysis spectra for specified thickness values D1 (thickness of Si3N4 layer) and D2 (thickness of SiO2 layer) and for the total optical thickness resulting therefrom:

D1	Specified thickness of first layer
D2	Specified thickness of second layer
Opt.Thick	Optical thickness, calculated from the sum of the products of the average refractive index and the thickness in the wavelength range from 200 nm to 800 nm, i.e. optical thickness = $[n1(\lambda)]D1 + [n2(\lambda)]D2$
NoE	Number of extremes
Mean	Mean of the calculated spectrum
Sigma	Standard deviation of the mean of the calculated spectrum
Min	Intensity value of the minimum in the wavelength range
Max	Intensity value of the maximum in the wavelength range
WL-MaxEX	Wavelength at which the last maximum occurs, beginning at the smallest wavelength (in nm)
MDEx	Mean distance of the extremes when more than one extreme is present (in nm)

Further useful curve shape parameters, especially for thicker layers, would be the values deriving from a fast Fourier transform, such as the locations of the

individual peaks and the summed peak. A search could also be made for the occurrence of beats, or for the location and intensity of the extremes that occur. The curve shape parameter list available to the evaluation software as a lookup table is reproduced below.

Table 1

Si3N4SiO2Si

Input		Output							
D1	D2	Opt. Thick	NoE	Mean	Sigma	Min	Max	Wl-MaxEX	MDEx
0	0	0	0	1.000	0.000	1.000	1.000	0	0
0	20	30	0	0.909	0.071	0.663	0.971	0	0
20	0	43	1	0.752	0.192	0.264	0.933	245	0
0	40	60	1	0.753	0.091	0.559	0.892	315	0
20	20	73	1	0.571	0.255	0.236	1.182	393	0
40	0	86	2	0.514	0.262	0.116	1.066	383	147
0	60	89	1	0.628	0.167	0.417	1.042	421	0
20	40	103	2	0.516	0.370	0.131	1.273	488	251
40	20	116	2	0.431	0.401	0.015	1.191	510	263
0	80	119	2	0.552	0.236	0.300	1.017	499	241
60	0	130	3	0.357	0.323	0.001	1.021	495	138
20	60	133	2	0.531	0.409	0.051	1.241	611	297
40	40	146	2	0.538	0.483	0.027	1.323	322	104
0	100	149	3	0.531	0.272	0.255	1.006	602	190
60	20	159	2	0.489	0.441	0.000	1.189	335	89
20	80	162	2	0.629	0.408	0.143	1.221	343	96
80	0	173	4	0.404	0.370	0.002	1.012	646	141
40	60	176	2	0.730	0.479	0.046	1.370	400	154
0	120	179	2	0.583	0.290	0.234	1.034	362	110

60	40	189	3	0.758	0.456	0.010	1.337	408	91
20	100	192	2	0.767	0.371	0.169	1.247	419	135
80	20	203	3	0.645	0.401	0.006	1.233	416	90
40	80	206	3	0.915	0.408	0.178	1.471	440	103
0	140	208	3	0.663	0.273	0.226	1.032	413	94
100	0	216	4	0.509	0.362	0.006	1.053	416	67
60	60	219	3	0.966	0.399	0.001	1.502	455	107
20	120	222	3	0.854	0.325	0.203	1.268	470	116
80	40	232	4	0.911	0.356	0.069	1.361	473	87
40	100	235	3	1.016	0.388	0.100	1.498	486	120
0	160	238	3	0.727	0.224	0.292	1.022	470	109
100	20	246	4	0.762	0.303	0.203	1.159	491	88
60	80	249	4	1.089	0.394	0.195	1.588	503	91
20	140	252	4	0.890	0.285	0.116	1.220	528	102
120	0	259	5	0.636	0.289	0.104	1.025	492	69
80	60	262	4	1.089	0.334	0.109	1.518	524	98
40	120	265	4	1.069	0.364	0.119	1.489	544	106
0	180	268	4	0.778	0.175	0.440	1.008	527	98
100	40	276	5	0.996	0.270	0.396	1.327	549	83
60	100	278	4	1.163	0.397	0.196	1.625	556	103
20	160	281	4	0.913	0.297	0.186	1.231	586	114
120	20	289	5	0.832	0.279	0.132	1.195	569	85
80	80	292	5	1.171	0.379	0.225	1.616	575	87
40	140	295	5	1.062	0.395	0.050	1.461	601	96
0	200	298	4	0.811	0.174	0.408	1.039	584	111
140	0	302	6	0.706	0.278	0.008	1.018	569	71
100	60	305	5	1.106	0.345	0.017	1.487	601	93
60	120	308	5	1.160	0.437	0.075	1.626	612	95

20	180	311	5	0.910	0.323	0.145	1.247	647	104
120	40	319	5	0.980	0.334	0.004	1.327	630	98
80	100	322	5	1.166	0.461	0.033	1.667	629	98
40	160	325	5	1.019	0.425	0.022	1.428	664	108
0	220	328	5	0.812	0.198	0.345	1.031	641	102
140	20	332	6	0.811	0.332	0.047	1.201	650	86
100	80	335	6	1.124	0.424	0.088	1.597	654	87
60	140	338	6	1.088	0.487	0.016	1.612	673	91
20	200	341	5	0.857	0.348	0.066	1.264	474	65
160	0	346	7	0.702	0.312	0.009	1.040	647	72
120	60	349	6	1.044	0.379	0.027	1.441	684	92
80	120	351	5	1.102	0.518	0.095	1.689	435	54
40	180	354	5	0.956	0.435	0.016	1.394	479	66
0	240	357	5	0.786	0.221	0.309	1.025	473	64
140	40	362	5	0.914	0.362	0.121	1.284	484	64
100	100	365	5	1.085	0.479	0.151	1.666	456	57
60	160	368	5	1.016	0.480	0.003	1.585	475	61
20	220	371	5	0.807	0.355	0.129	1.225	514	72
160	20	375	6	0.758	0.350	0.019	1.151	495	54
120	80	378	6	1.036	0.424	0.159	1.557	487	53
80	140	381	6	1.022	0.519	0.029	1.689	473	51
40	200	384	5	0.889	0.438	0.016	1.396	522	73
0	260	387	5	0.756	0.236	0.286	1.043	510	69
180	0	389	7	0.655	0.340	0.001	1.026	491	47
140	60	392	6	0.953	0.395	0.053	1.403	517	59
100	120	395	6	1.014	0.503	0.151	1.703	485	53
60	180	398	6	0.949	0.463	0.000	1.553	518	60
20	240	401	5	0.778	0.359	0.129	1.246	553	77

160	40	405	6	0.841	0.384	0.018	1.342	538	62
120	100	408	6	0.994	0.452	0.002	1.638	514	56
80	160	411	6	0.949	0.491	0.006	1.675	514	57
40	220	414	6	0.836	0.440	0.017	1.455	564	68
0	280	417	6	0.730	0.238	0.270	1.035	548	65
180	20	419	7	0.703	0.366	0.007	1.169	548	55
140	80	422	7	0.944	0.417	0.016	1.507	546	55
100	140	424	7	0.925	0.499	0.009	1.716	519	51
60	200	427	7	0.879	0.458	0.000	1.487	561	58
20	260	430	6	0.751	0.362	0.044	1.263	593	72
200	0	432	7	0.614	0.336	0.000	1.017	543	53
160	60	435	7	0.884	0.403	0.001	1.482	574	59
120	120	438	7	0.931	0.449	0.017	1.674	541	54
80	180	441	7	0.886	0.454	0.000	1.614	556	57
40	240	444	7	0.803	0.447	0.021	1.486	605	66
0	300	447	6	0.702	0.235	0.257	1.031	586	70
180	40	448	7	0.790	0.400	0.046	1.363	593	62
140	100	451	7	0.916	0.406	0.141	1.549	573	58
100	160	454	7	0.855	0.456	0.027	1.665	556	55
60	220	457	7	0.834	0.451	0.000	1.527	605	64
20	280	460	7	0.724	0.369	0.098	1.263	633	69
200	20	462	8	0.658	0.366	0.002	1.202	600	55
160	80	465	8	0.886	0.401	0.098	1.537	604	55
120	140	468	8	0.847	0.430	0.045	1.633	572	51
80	200	471	7	0.830	0.424	0.001	1.465	599	63
40	260	474	7	0.784	0.462	0.025	1.498	647	71
220	0	475	8	0.563	0.327	0.001	1.034	595	53
180	60	478	8	0.835	0.423	0.060	1.515	630	59

140	120	481	8	0.856	0.383	0.106	1.511	600	55
100	180	484	8	0.795	0.408	0.006	1.529	596	54
60	240	487	7	0.808	0.466	0.000	1.572	648	69
20	300	490	7	0.707	0.383	0.135	1.239	672	74
200	40	492	8	0.741	0.422	0.028	1.358	648	61
160	100	495	8	0.852	0.395	0.026	1.517	632	58
120	160	497	8	0.759	0.407	0.033	1.507	605	54
80	220	500	8	0.781	0.428	0.002	1.466	643	60
40	280	503	8	0.769	0.483	0.030	1.498	689	67
220	20	505	9	0.608	0.383	0.000	1.189	653	55
180	80	508	9	0.835	0.436	0.007	1.585	663	56
140	140	511	9	0.763	0.378	0.003	1.390	628	52
100	200	514	9	0.734	0.389	0.000	1.290	638	54
60	260	517	8	0.794	0.500	0.000	1.602	691	67
240	0	518	9	0.517	0.335	0.002	1.026	647	53
200	60	521	9	0.801	0.457	0.014	1.521	687	59
160	120	524	9	0.794	0.390	0.005	1.437	660	56
120	180	527	9	0.695	0.384	0.006	1.331	641	54
80	240	530	8	0.762	0.464	0.003	1.534	686	65
40	300	533	8	0.773	0.496	0.026	1.492	730	72
220	40	535	9	0.722	0.444	0.010	1.343	702	60
180	100	538	9	0.821	0.440	0.035	1.588	692	59
140	160	541	9	0.694	0.364	0.036	1.284	658	55
100	220	544	9	0.709	0.400	0.001	1.317	681	58
60	280	546	9	0.808	0.524	0.001	1.620	734	65
240	20	548	10	0.599	0.399	0.000	1.160	706	54
200	80	551	10	0.834	0.472	0.042	1.609	721	56
160	140	554	10	0.739	0.373	0.016	1.322	687	53

120	200	557	9	0.669	0.381	0.009	1.290	680	58
80	260	560	9	0.789	0.499	0.003	1.587	730	64
260	0	562	10	0.503	0.351	0.004	1.018	699	53
220	60	565	10	0.822	0.473	0.013	1.513	743	58
180	120	567	10	0.801	0.437	0.076	1.535	720	56
140	180	570	10	0.660	0.375	0.061	1.341	691	53
100	240	573	9	0.736	0.435	0.003	1.407	724	62
60	300	576	8	0.862	0.514	0.002	1.628	568	49
240	40	578	9	0.756	0.447	0.010	1.323	562	43
200	100	581	10	0.855	0.474	0.066	1.634	751	59
160	160	584	10	0.704	0.374	0.007	1.229	715	55
120	220	587	10	0.683	0.402	0.001	1.299	721	56
80	280	590	9	0.848	0.502	0.003	1.626	571	45
260	20	591	10	0.632	0.401	0.000	1.191	571	40
220	80	594	10	0.888	0.477	0.025	1.616	572	40
180	140	597	11	0.776	0.426	0.019	1.440	747	54
140	200	600	10	0.653	0.406	0.035	1.420	727	56
100	260	603	9	0.796	0.454	0.005	1.484	577	45
280	0	605	11	0.530	0.358	0.004	1.031	752	53
240	60	608	10	0.890	0.448	0.043	1.497	588	41
200	120	611	10	0.864	0.462	0.036	1.604	580	41
160	180	614	11	0.695	0.394	0.012	1.360	746	54
120	240	617	10	0.737	0.415	0.000	1.273	763	60
80	300	619	9	0.916	0.477	0.028	1.654	600	47
260	40	621	10	0.821	0.411	0.007	1.344	602	43
220	100	624	10	0.934	0.461	0.000	1.658	595	42
180	160	627	10	0.770	0.401	0.002	1.324	597	42
140	220	630	10	0.689	0.416	0.014	1.447	603	43

100	280	633	10	0.866	0.440	0.011	1.546	605	43
280	20	635	11	0.686	0.370	0.010	1.202	610	40
240	80	638	11	0.973	0.434	0.011	1.610	612	40
200	140	640	11	0.859	0.436	0.003	1.531	607	40
160	200	643	10	0.709	0.407	0.002	1.460	616	44
120	260	646	10	0.814	0.392	0.006	1.330	615	44
300	0	648	11	0.577	0.339	0.001	1.025	608	39
260	60	651	11	0.960	0.400	0.004	1.475	629	41
220	120	654	11	0.948	0.445	0.011	1.649	621	41
180	180	657	11	0.778	0.381	0.001	1.297	626	42
140	240	660	10	0.760	0.387	0.006	1.433	629	45
100	300	663	10	0.927	0.426	0.111	1.596	635	46
280	40	664	11	0.871	0.371	0.049	1.361	643	43
240	100	667	11	1.008	0.439	0.087	1.669	637	42
200	160	670	11	0.850	0.403	0.004	1.432	636	42
160	220	673	11	0.741	0.399	0.034	1.519	644	43
120	280	676	11	0.877	0.373	0.035	1.411	644	43
300	20	678	12	0.724	0.345	0.011	1.189	650	40
260	80	681	12	1.023	0.420	0.051	1.599	653	40
220	140	684	12	0.926	0.448	0.022	1.602	647	40
180	200	687	11	0.784	0.380	0.004	1.426	655	44
140	260	690	11	0.826	0.352	0.062	1.383	657	44
280	60	694	12	0.989	0.391	0.035	1.504	670	42
240	120	697	12	0.998	0.460	0.077	1.680	661	41
200	180	700	12	0.843	0.376	0.000	1.331	664	41
160	240	703	11	0.786	0.383	0.024	1.538	671	45
120	300	706	11	0.911	0.393	0.002	1.481	672	45
300	40	708	12	0.888	0.368	0.036	1.363	683	43

260	100	711	12	1.035	0.454	0.015	1.671	678	42
220	160	713	12	0.896	0.437	0.004	1.522	674	42
180	220	716	12	0.794	0.389	0.009	1.519	684	43
140	280	719	12	0.864	0.348	0.005	1.309	684	43
280	80	724	13	1.031	0.434	0.004	1.582	695	40
240	140	727	12	0.958	0.476	0.017	1.652	686	43
200	200	730	12	0.835	0.371	0.000	1.339	694	44
160	260	733	12	0.830	0.370	0.003	1.522	699	44
300	60	737	13	0.985	0.405	0.019	1.517	711	41
260	120	740	13	1.008	0.482	0.009	1.697	702	41
220	180	743	12	0.874	0.413	0.000	1.423	703	44
180	240	746	12	0.812	0.401	0.023	1.574	713	45
140	300	749	12	0.882	0.368	0.034	1.335	711	45
280	100	754	13	1.025	0.470	0.018	1.664	718	42
240	160	757	13	0.910	0.474	0.027	1.592	713	42
200	220	760	13	0.827	0.388	0.001	1.462	723	42
160	280	762	13	0.855	0.366	0.002	1.477	725	43
300	80	767	14	1.008	0.447	0.018	1.585	736	40
260	140	770	13	0.952	0.495	0.002	1.686	727	42
220	200	773	13	0.847	0.401	0.001	1.351	732	43
180	260	776	13	0.827	0.413	0.064	1.593	740	44
280	120	784	13	0.984	0.489	0.046	1.703	587	31
240	180	786	13	0.869	0.453	0.004	1.508	741	44
200	240	789	12	0.821	0.413	0.008	1.551	620	37
160	300	792	12	0.856	0.373	0.009	1.412	617	36
300	100	797	13	0.991	0.471	0.048	1.651	604	33
260	160	800	13	0.892	0.485	0.014	1.643	591	31
220	220	803	13	0.824	0.403	0.001	1.366	618	34

180	280	806	13	0.831	0.418	0.022	1.585	636	35
280	140	813	13	0.921	0.485	0.016	1.706	603	32
240	200	816	13	0.833	0.427	0.000	1.432	614	33
200	260	819	13	0.817	0.434	0.025	1.607	646	36
300	120	827	13	0.946	0.472	0.029	1.701	620	34
260	180	830	13	0.842	0.460	0.006	1.576	614	33
220	240	833	13	0.812	0.412	0.000	1.484	647	36
180	300	835	13	0.828	0.412	0.011	1.550	657	37
280	160	843	14	0.855	0.464	0.004	1.680	622	31
240	220	846	14	0.804	0.411	0.001	1.447	644	33
200	280	849	14	0.808	0.449	0.009	1.632	670	35
300	140	856	14	0.877	0.461	0.007	1.716	636	32
260	200	859	14	0.799	0.433	0.001	1.489	641	33
220	260	862	14	0.803	0.436	0.004	1.571	675	36
280	180	873	14	0.798	0.439	0.011	1.613	644	33
240	240	876	14	0.789	0.413	0.002	1.407	673	35
200	300	879	14	0.799	0.453	0.037	1.629	693	37
300	160	886	15	0.808	0.432	0.003	1.661	654	32
260	220	889	15	0.768	0.415	0.002	1.509	669	33
220	280	892	15	0.791	0.464	0.016	1.628	702	35
280	200	903	15	0.754	0.420	0.005	1.460	668	32
240	260	906	15	0.786	0.434	0.000	1.498	703	35
300	180	916	15	0.754	0.403	0.002	1.521	674	33
260	240	919	15	0.759	0.417	0.004	1.503	699	35
220	300	922	15	0.787	0.482	0.004	1.656	727	37
280	220	932	16	0.729	0.412	0.000	1.527	695	32
240	280	935	16	0.791	0.463	0.002	1.583	731	35
300	200	946	16	0.715	0.401	0.011	1.393	697	32

260	260	949	16	0.772	0.437	0.003	1.447	729	35
280	240	962	16	0.734	0.424	0.003	1.557	724	34
240	300	965	16	0.804	0.487	0.007	1.639	757	36
300	220	976	17	0.701	0.417	0.002	1.510	723	32
260	280	979	17	0.798	0.459	0.001	1.507	758	34
280	260	992	17	0.766	0.441	0.005	1.537	754	34
300	240	1005	17	0.724	0.433	0.001	1.574	750	34
260	300	1008	16	0.836	0.464	0.001	1.590	643	29
280	280	1022	17	0.814	0.442	0.004	1.472	651	28
300	260	1035	17	0.773	0.436	0.005	1.589	659	28
280	300	1051	17	0.864	0.425	0.002	1.514	670	29
300	280	1065	18	0.829	0.420	0.013	1.561	678	28
300	300	1095	18	0.876	0.405	0.006	1.493	696	28

The measured spectra depicted in FIG. 1 can be acquired, for example, using an optical measurement device such as the one known from DE 100 21 379 A1 discussed above. The reader is referred to that document for complete details of the measurement procedure. According to the present invention, the characteristic curve shape parameters cited in this example are derived from the acquired measured spectrum, and the results are compared to the values in the table above. The result then obtained is one or more optical thicknesses, and thus layer thickness combinations, for which there is a particularly good match between the curve shape parameters derived from the measured spectrum and the calculated parameters of the list. For those thickness combinations, associated analysis spectra are then calculated and are compared to an acquired measured spectrum as depicted in FIG. 1a. Since it usually cannot be assumed that the thickness combination discovered using the method according to the present invention already corresponds to the one that is present, known coarse and fine fitting procedures, such as grid, interval, and Powell methods, then advantageously follow for determination of the exact layer thicknesses. In this case the method

according to the present invention serves to restrict the parameter space so that the subsequent fitting procedures reach their goal considerably faster.

It is advantageous to add further known methods as well as the method according to the present invention for restricting the parameter space, especially in order, for example, to exclude discovered layer thickness combinations (D1, D2) as implausible. The extremes method and Fourier transform method already mentioned can, in particular, be used for this purpose.

FIGS. 2 through 5 show how specified values of optical parameters (in this case, layer thickness combinations) can be associated with certain characteristic curve shape parameters of the acquired measured curve. In FIG. 2, the correlation is approximately linear, i.e. the number of extremes increases in proportion to the optical thickness. The "Mean" parameter (FIG. 3) changes with optical thickness in the form of a damped oscillation; although the fluctuation range decreases with increasing optical thickness, the mean also continuously approaches a constant. This of course also reflects the spectral resolution of the measurement apparatus, and therefore the scanning theorem. The parameter WLMaxEx plotted against optical thickness in FIG. 4 describes the location of the longest-wave maximum. These values are of course also limited by the wavelength range of the measurement apparatus (here between 200 nm and 800 nm). Curves that do not exhibit a unequivocal maximum (boundary wavelengths are excluded and extremes must exceed a predefined threshold value) have zero assigned to them as parameter value. Proceeding from an optical thickness of zero, this value rises until the extreme has, so to speak, migrated out of the measurement range. FIG. 5 shows that in the optical thickness range indicated, the Maximum (intensity) Value parameter oscillates approximately from one value to the next.

The overall conclusion is that assignment of an optical thickness by way of a single value obtained from the measured curve is ambiguous. Several such values must therefore be utilized. The fluctuation ranges in the individual curves indicate the different degrees to which the parameter value ranges need to be restricted. The possibility for restriction, and therefore for filtering, is illustrated by the horizontal lines in the Figures as an example of one possible evaluation variant.

In general: from the assigned values it is possible (even using other known methods) to select the most probable ones and to use those to calculate an analysis spectrum.

Simplified exemplary embodiment of a filter:

A spectrum (175 nm Si_3N_4 on 190 nm SiO_2) that does not correspond to the one depicted in FIG. 1a yields the target values listed in Table 2, column 1, "Target value."

If the filter ranges indicated in Table 2 (corresponding to the horizontal lines in FIGS. 2 through 5) are sequentially selected out of the 256 list entries originally provided in Table 1, the number of list entries is successively reduced from an initial 63 to four.

The spectra associated with these list entries are depicted in FIG. 6 together with the target spectrum (175-190).

The best match is obtained for the adjacent curves having layer thicknesses (180-180) and (160-200).

Table 2. Reduction using filters. Initial value = 256 list entries

Target value	Filter step / Filter name	Filter range	No. of list entries
11	1 / NoE	10-12	63
628	2 / WL-Max	613 - 643	12
1.4	3 / Max	1.25 – 1.55	9
0.78	4 / Mean	0.74 – 0.82	4

A coarse fit in the indicated thickness ranges (e.g. increment ±20 nm in each case) leads to a result with a good curve shape match for the table entry with thicknesses D1 = D2 = 180 nm. A subsequent fine fit using a grid, interval, or Powell method yields a result with the desired accuracy (e.g. 0.1 nm).

For simplicity's sake, the example above is limited to determining only the layer thicknesses of a double layer. The manner in which the example can be extended

to the determination of further optical parameters, such as the refractive index n or extinction coefficient k, will be evident to one skilled in the art.

In particular, it is also possible with the aforesaid method according to the present invention to preselect the relevant layer types (chemical composition), in which context a selection must be made from a correspondingly larger parameter space (parameter lists for different single- or multiple-layer compositions). An a priori limitation is, however, usually possible, since the customer (user) in most cases knows which possible combinations may occur. For example, the determination of the combination that is present (i.e. the sequence of layer compositions) can be made in the background while stage positions are being programmed in for the next measurement. Before the actual measurement of optical parameters begins, the resulting combination is then presented to the customer (user), who can accept or correct it.